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LIME AND PHOSPHORUS INTERACTIONS ON GROWTH AND NUTRIENT UPTAKE BY UPLAND RICE, WHEAT, COMMON BEAN, AND CORN IN AN OXISOL

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ABSTRACT: Liming and phosphorus (P) applications are common practices for improving crop production in acid soils of the tropical as well as temperate regions. Four greenhouse experiments were conducted on an Oxisol (clayey, kaolinitic, isothermic, Typic Haplustox) to evaluate response of liming (0, 2, and 4 g/kg) and P application (0, 50, and 175 mg P/kg) in a factorial combination on growth and nutrient uptake by upland rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.), common bean (*Phaseolus vulgaris* L.), and corn (*Zea mays* L.). Phosphorus application significantly ($P<0.01$) increased dry weight of tops of all the four crop species as well as dry weight of roots of wheat and corn. Liming significantly ($P<0.01$) improved growth of common bean and corn but had significant negative effects on rice growth. Maximum dry weight of tops of rice and wheat was obtained at 175 mg P/kg without lime. Maximum dry weight of tops in common bean was obtained at 4 g lime/kg with 175 mg P/kg of soil. In all the crops, increasing levels of applied P significantly increased nutrient uptake. With some exceptions, increasing levels of lime tend to reduce uptake of P, zinc (Zn), copper (Cu), manganese (Mn), and iron (Fe) and increase the uptake of calcium (Ca) and magnesium (Mg) in all the crop species. Decrease in potassium (K) uptake, due to high lime, is probably due to antagonistic effects of Ca and Mg and reduced micronutrients uptake is probably due to increased soil pH resulting in decreased

availability of these elements to plants. Therefore, in these types of acid soils, one should avoid over liming.

INTRODUCTION

In highly weathered, acid soils around the world, P, Ca, and Mg deficiencies and aluminum (Al) and Mn toxicities are the most important nutritional and/or element disorders that limit the crop yields (Fageria, 1989; 1992; Fageria et al., 1989; Parker et al., 1989; Foy, 1992; Fageria, 1994). Such soils, crop yield responses to lime and P are often interdependent (Friesen et al., 1980). An increasing response to applied P with increasing rates of added lime have been attributed to either an improved rate of supply of P by the soil or an improved ability of the plant to absorb P when Al toxicity has been eliminated (Friesen et al., 1980). Liming also improves microbiological activities of acid soils, which in turn can increase dinitrogen fixation by legumes and liberate nitrogen (N) from incorporated organic materials.

However, over liming may reduce crop yields due to lime induced P and micronutrient deficiencies (Fageria, 1984). When soil pH increased in an Oxisol more than six, the soluble P forms a complex with Ca, and consequently P availability is decreased (Fageria, 1984). Similarly, increase in one unit of pH in acid soil can reduce Fe concentration in the soil solution about 1000-fold and other micronutrients, such as Cu and Zn about 100 times (Lindsay, 1979). In an Oxisol of Central Brazil, when pH is raised more than six through liming, Fe deficiency is a common nutritional disorder observed in upland rice (Fageria et al., 1990). This deficiency is not due to low level of Fe in the soil but due Fe precipitation as $\text{Fe}(\text{OH})_3$, and consequently, unavailability of this element to plants (Fageria et al., 1990). Under these situations, an appropriate combination of lime and P is an important strategy for improving field crops yield in highly weathered Oxisols.

The objective of the work reported here was to study the effects of lime and P and their interactions on the growth and nutrient uptake by rice, wheat, common bean, and corn on an Oxisol under greenhouse conditions.

MATERIALS AND METHODS

Four greenhouse experiments were conducted using a dark red latosol [clayey, kaolinite, isothermic Typic Haplustox (Oxisol) in soil taxonomy]. The soil used in the four experiments had the following chemical properties before the application of lime and P: pH = 4.8 (1:2.5 soil-water ratio); extractable P = 1.9 mg/kg; and

extractable cations were K = 62 mg/kg; Ca = 0.6 cmol/kg; Mg = 0.5 cmol/kg; Al = 1 cmol/kg; Zn = 1.4 mg/kg; Fe = 120 mg/kg; Mn = 20 mg/kg; and Cu = 1.4 mg/kg. Phosphorus and K were extracted by the Mehlich 1 extracting solution (0.05M HCl in 0.0125M H₂SO₄). Phosphorus was determined colorimetrically and K by flame photometry. Calcium, Mg, and Al were extracted with 1M KCl. Aluminum was determined by titration with NaOH and Ca and Mg by titration with EDTA. Micronutrients were determined on a portion of the extract of P by atomic absorption spectrophotometry. Soil analysis methods used in this study are described in a soil analysis manual published by EMBRAPA (1979).

The treatment consisted of three lime levels (L), i.e., 0, 2, and 4 g/kg and three P levels, i.e., 0, 50, and 175 mg/kg of soil. A complete randomized design was used in a factorial arrangement and treatments were replicated four times in rice and common bean and three times in the case of wheat and corn. Studies were conducted in plastic pots with 5 kg of soil in each pot. The lime used had CaO = 4.93%; MgO = 2.8%; CaCO₃ = 88%; MgCO₃ = 5.9%; and neutralizing power of CaCO₃ = 74%. Limestone was applied 60 days before planting. All the pots were subjected to wetting and drying cycles during the incubation period. At the time of sowing the four crops, P was applied as triple superphosphate. Each pot received a basal application of 520 mg N as ammonium sulfate, 593 mg K as potassium chloride, and 0.75 g FTE-BR-12 fritted glass material as a source of micronutrients (Fageria and Souza, 1991). Cultivars used were: rice, Caiapo; common bean, Carioca; wheat, BH11-46; and corn, BR106. For rice and wheat, four plants per pot and three plants per pot for common bean and corn were maintained. Each pot was frequently watered with distilled water to maintain moisture, approximately at field capacity, during the crop growth period. Rice was harvested at 54 days after sowing, common bean at 36 days after sowing, wheat at 41 days after sowing, and corn at 28 days after sowing.

After harvesting the tops, the roots of wheat and corn were removed from soil using water jet. Tops, as well as roots, were washed with distilled water several time before drying. Plant material (roots and tops) was dried in a forced-draft oven at about 70°C until a constant weight and milled. Ground material was digested with mixtures of nitric and perchloric acids (2:1). The P concentration in the digest was determined colorimetrically, while all other elements were determined by atomic absorption spectrophotometry (Moraes and Rabelo, 1986). After harvesting corn, soil samples were taken from each pot to evaluate soil properties. All the data

were analyzed by analysis of variance and F-test was used to evaluate treatments significance.

RESULTS AND DISCUSSION

Dry Weight of Tops and Roots

Phosphorus and lime application significantly increased top yields of common bean and corn (Table 1). Application of 175 mg P/kg without lime gave the highest yield for rice and wheat. At this level of P, rice top yields increased by 26-fold, and wheat top yields increased by 49-fold over control. In common bean, maximum top yields were achieved at 175 mg/kg of P and 4 g lime/kg. The extreme deficiency of P in the soil used was evident in the lowest dry matter accumulation of shoot and roots of all crops at all levels of lime with no added P.

Increasing levels of lime significantly decreased top dry matter of rice and wheat but significantly increased the top dry matter accumulation in common bean, and to some extent, in corn. Lime and P interactions for top weights were significant for rice, common bean, and corn. With the exception of common bean, higher levels of lime appear to be detrimental in improvement of top weight. The negative effects of lime on rice and wheat growth may be related to tolerance of these two crop species to soil acidity (Fageria et al., 1991). The cultivars used for rice and wheat appears to be highly tolerant to soil acidity. Rajaram et al. (1990) state that Brazilian wheat cultivars are most tolerant to soil acidity, and therefore, they are widely used world wide in breeding programs to develop modern, high-yielding cultivars for tropical, acid soils.

Response surface equations were formulated to evaluate the effect of lime and P effects on top dry weight of four crops. These equations were:

$$\text{Rice} = 18.59 - 1.93 L - 0.33 L^2 + 7.21 P - 10.76 P^2 - 1.05 LP$$

$$\text{Wheat} = 4.91 - 0.42 L - 0.13 L^2 + 1.40 P - 3.06 P^2 + 0.12 LP$$

$$\text{Common Bean} = 12.13 + 0.71 L - 0.44 L^2 + 4.82 P - 6.19 P^2 + 0.15 LP$$

$$\text{Corn} = 6.50 + 0.47 L - 0.03 L^2 + 2.08 P - 2.87 P^2 + 0.39 LP$$

Root dry weights of wheat and corn significantly ($P < 0.05$) improved due to P application (Table 1). The highest root weight for wheat was obtained with 50 mg P/kg alone, whereas the highest corn roots were observed for 175 mg P/kg with 4 g lime/kg. In fact, increasing levels of lime had a detrimental effect on dry weight of

wheat root, however, increasing lime slightly improved dry weight of corn roots. Both crops showed no effect of lime and P interaction on root weight.

Nutrient Uptake

Uptake of Ca, Mg, Zn, Cu, Mn, and Fe, in all four crops, significantly increased with increasing levels of applied P (Tables 2, 3, 4, and 5). Such an increase in nutrient uptake is related to positive significant response of top weight to applied P in all four species. Even though lime application significantly effected nutrient uptake in all the crops, invariably increasing levels of applied lime, with the exception of Ca and Mg, tend to reduce the uptake of other nutrients. The decrease in K uptake with lime addition may be related to antagonistic effect of Ca and Mg on uptake of K (Fageria, 1983). The decrease in micronutrient uptake with increasing lime may be related to increasing soil pH (Albasel and Cottenic, 1985) and decrease in concentration of these elements in soil solution (Lindsay, 1979).

Among four crop species, rice removed more nutrients (Table 2) and wheat removed relatively less nutrients (Table 3) than common bean (Table 4) and corn (Table 5).

Soil Chemical Properties

Chemical properties of soil were determined after the harvest of corn (Table 6). Lime and P application, alone or in combination, significantly increased soil pH. Soil pH increased from 4.4 (control) to 5.6 in a treatment receiving 4 g lime/kg and 175 mg P/kg. Overall, increasing levels of lime enhanced extractable nutrients, and lime effect was significant for K, Ca, Mg, and Mn. However, increasing levels of added lime and P increased extractable P. Improvement in extractable P may be related to neutralizing of Al content. In acid soils, the oxides, hydroxides, and oxy-hydroxides of Fe and Al are known to influence P sorption (Yuan and Lavkulich, 1994). Increasing levels of P reduced extractable K, but increasing lime levels tend to improve extractable K status. Increasing levels of lime significantly ($P < 0.01$) reduced extractable Al. Overall, P and lime interaction gave nonsignificant effect on extractable Al. This suggests that in this soil added P had little ameliorating effect on extractable Al. Friesen et al. (1980) reported a similar observation in two Nigerian Ultisols. Application of 4 g lime/kg practically neutralized all the Al. Lime and P application had no significant effect on extractable Zn and Cu.

CONCLUSIONS

Obtained results show that P deficiency in soil is the most important growth limiting factor in Oxisols of Central Brazil. Lime addition had a positive effect on

TABLE 1. Dry matter yield of tops and roots of four crop species as affected by lime and phosphorus treatments.

Lime g kg ⁻¹	Phosphorus mg kg ⁻¹	Rice	Wheat	Common Bean	Corn	Wheat	Corn
		Shoot DW g pot ⁻¹				Root DW g pot ⁻¹	
0	0	0.72	0.17	1.25	1.10	0.53	1.63
0	50	15.08	5.83	8.30	4.93	4.83	4.57
0	175	18.63	8.40	10.60	8.73	3.00	4.80
2	0	0.73	0.20	1.30	1.43	0.27	1.77
2	50	15.23	5.20	9.00	7.13	3.43	4.60
2	175	13.23	6.50	10.60	11.47	3.76	6.00
4	0	0.33	0.20	1.70	1.10	0.30	1.20
4	50	10.20	4.90	10.50	6.60	2.70	6.03
4	175	13.20	5.97	12.00	9.93	2.73	6.30

<u>F-test</u>						
Lime	**	*	**	**	NS	NS
Phosphorus	**	**	**	**	**	**
Lime X P	**	NS	*	*	NS	NS
C.V. %	10.56	19.53	7.47	11.16	39.23	26.17
<u>Average across the lime (L) and P level</u>						
L ₀	11.47 a	4.80 a	6.68 b	4.92 c	2.80 a	3.67 a
L ₂	9.73 b	2.97 ab	6.93 b	6.68 a	2.49 a	4.12 a
L ₄	7.91 c	3.69 b	8.07 a	5.88 b	1.91 a	4.51 a
P ₀	0.59 c	0.19 c	1.14 c	1.21 c	0.37 b	1.21 c
P ₅₀	13.50 b	5.31 b	9.22 b	6.22 b	3.67 a	6.22 b
P ₁₇₅	15.02 a	6.96 a	11.06 a	10.04 a	3.17 a	10.04 a

*, **Significant at the 0.05 and 0.01 probability levels, respectively. NS = Not significant.

Within column means followed by a different letter differ significantly at $P < 0.05$ by Tukey's studentized range test.

TABLE 2. Influence of lime and phosphorus on nutrient uptake in rice.

Lime g kg ⁻¹	Phosphorus mg kg ⁻¹	P	K	Ca	Mg	Zn	Cu	Mn	Fe
		-----mg pot ⁻¹ -----			-----	-----μg pot ⁻¹ -----			
0	0	0.5	20	2.6	1.9	201	6	1418	243
0	50	34.6	539	41.4	42.5	3324	260	14362	3128
0	175	73.3	624	53.8	61.5	3910	311	15355	3728
2	0	0.7	20	3.4	2.1	142	7	1322	165
2	50	39.6	431	73.8	57.4	2740	164	12892	2401
2	175	52.9	360	68.9	43.8	1871	144	8635	2211
4	0	0.3	8	3.0	1.5	39	2	207	77
4	50	26.7	270	52.3	41.3	902	88	3043	1510
4	175	46.6	385	61.0	57.0	1226	109	3758	1810
F-Test									
Lime		**	**	**	NS	**	**	**	**
Phosphorus		**	**	**	**	**	**	**	**
Lime X P		**	*	*	**	**	**	**	**
C.V. %		13.45	15.43	20.18	18.23	33.12	17.79	21.42	13.72
Average across the lime (L) and P levels									
L ₀	36.1a	395a	32.6a	35.3a	2485a	193a	10379a	2367a	
L ₂	31.1a	271b	48.7a	34.4a	1335b	105b	7617b	1592b	
L ₄	24.5c	221c	38.7b	33.3a	724c	67c	2336c	1133c	
P ₀	0.5c	16b	3.0b	1.9c	128b	5b	983b	162c	
P ₅₀	33.6b	413a	55.9a	47.1b	1078a	171a	10099a	2347b	
P ₁₇₅	57.6a	457a	61.2a	54.1a	2336a	188a	9249a	2583a	

*, **Significant at the 0.05 and 0.01 probability levels, respectively. NS = Not significant.

Within column means followed by a different letter differ significantly at $P < 0.05$ by Tukey's studentized range test.

TABLE 3. Influence of lime and phosphorus on nutrient uptake in wheat.

Lime g kg ⁻¹	Phosphorus mg kg ⁻¹	P	K	Ca	Mg	Zn	Cu	Mn	Fe
		-----	mg pot ⁻¹	-----		-----	μg pot ⁻¹	-----	
0	0	0.1	7	0.5	0.3	69	35	79	85
0	50	14.1	268	17.7	8.9	758	237	1481	1051
0	175	29.7	364	36.6	14.1	1090	334	2100	1780
2	0	0.4	8	0.8	0.7	28	2	85	38
2	50	16.3	252	29.9	14.2	410	56	1387	815
2	175	26.4	278	43.7	19.8	496	65	1740	1034
4	0	0.2	7	1.4	0.8	12	1	66	31
4	50	14.3	213	30.4	13.2	232	40	637	692
4	175	23.5	274	40.8	19.5	292	59	934	1481

F-Test

Lime	NS	*	*	*	**	*	**	NS
Phosphorus	**	**	**	**	**	NS	**	**
Lime X P	NS	NS	NS	NS	**	NS	**	NS
C.V. %	20.3	19	20.6	26.5	34.8	32.3	20	45

Average across the lime (L) and P levels

L ₀	14.6a	213a	18.3b	7.8b	639a	202a	1220a	1072a
L ₂	14.4a	179ab	24.9a	14.5a	311b	41a	1071a	629a
L ₄	12.7a	165b	24.2a	11.2a	178b	34a	546b	735a
P ₀	0.2c	8c	1.0c	0.6c	36c	13a	77c	52c
P ₅₀	14.9b	244b	26.0b	12.1b	467b	111a	1168b	953b
P ₁₇₅	26.5a	305a	40.4a	17.8a	626a	153a	1591a	1432a

*, **Significant at the 0.05 and 0.01 probability levels, respectively. NS = Not significant.

Within column means followed by a different letter differ significantly at $P < 0.05$ by Tukey's studentized range test.

TABLE 4. Influence of lime and phosphorus on nutrient uptake in common bean.

Lime g kg ⁻¹	Phosphorus mg kg ⁻¹	P	K	Ca	Mg	Zn	Cu	Mn	Fe
		-----mg pot ⁻¹ -----			-----μg pot ⁻¹ -----				
0	0	2.7	39	24	5	458	7	803	442
0	50	10.8	351	97	34	982	33	3692	1154
0	175	25.9	393	114	38	683	44	4440	1518
2	0	1.2	30	34	8	158	8	201	269
2	50	18.3	287	150	45	373	26	783	983
2	175	25.9	345	195	55	393	45	1034	1246
4	0	1.2	37	58	10	130	11	134	292
4	50	21.4	314	199	56	324	32	471	1100
4	175	28.8	376	274	66	379	45	573	1418

F-Test

Lime	**	**	**	**	**	NS	**	NS
Phosphorus	**	**	**	**	**	**	**	**
Lime X P	**	NS	**	**	**	NS	**	NS
C.V. %	14.5	11	17	9	16	43	24	25

Average across the lime (L) and P levels

L ₀	13.1b	261a	78c	26c	733a	28a	2978a	1038a
L ₂	15.1ab	220b	126b	36b	308b	26a	672b	833a
L ₄	17.2a	242ab	177a	44a	278b	29a	393b	937a
P ₀	1.7c	35c	38c	7c	249b	9c	379c	335c
P ₅₀	16.9b	317b	149b	45b	560a	30b	1649b	1079b
P ₁₇₅	26.9a	371a	194a	53a	570a	45a	2016a	1394a

*, **Significant at the 0.05 and 0.01 probability levels, respectively. NS = Not significant.

Within column means followed by a different letter differ significantly at $P < 0.05$ by Tukey's studentized range test.

TABLE 5. Influence of lime and phosphorus on nutrient uptake in corn.

Lime g kg ⁻¹	Phosphorus mg kg ⁻¹	P	K	Ca	Mg	Zn	Cu	Mn	Fe
		-----mg pot ⁻¹ -----			-----µg pot ⁻¹ -----				
0	0	1.1	52	5.6	3.2	408	51	615	274
0	50	8.1	209	19.4	9.9	346	34	1500	575
0	175	20.6	388	38.8	18.9	1280	104	783	1021
2	0	1.4	60	11.2	5.9	270	30	470	262
2	50	10.7	288	52.0	26.1	796	45	1583	784
2	175	27.7	476	63.2	39.6	1522	102	1852	1177
4	0	0.9	52	11.4	4.6	161	11	220	270
4	50	9.5	273	52.7	28.8	345	121	619	573
4	175	20.8	411	71.8	39.4	739	163	1081	1018
F-Test									
Lime		NS	**	**	**	**	NS	**	NS
Phosphorus		**	**	**	**	**	**	**	**
Lime X P		*	NS	**	**	NS	NS	**	NS
C.V. %		21.1	11	9.9	14.4	33	71	16	17
Average across the lime (L) and P levels									
L ₀		11.1a	216b	21.3b	10.5b	845a	63a	1488a	623a
L ₂		13.3a	275a	42.2a	23.9a	863a	59a	1302a	741a
L ₄		10.4a	245ab	45.3a	24.3a	415b	98a	640b	620a
P ₀		2.4c	55c	9.4c	4.5c	280c	31b	435c	269c
P ₅₀		9.4b	256b	41.4b	21.6b	662b	67ab	1234b	644b
P ₁₇₅		23.1a	425a	57.9a	32.6a	1180a	123a	1761a	1072a

*, **Significant at the 0.05 and 0.01 probability levels, respectively. NS = Not significant.

Within column means followed by a different letter differ significantly at P < 0.05 by Tukey's studentized range test.

TABLE 6. Selected soil chemical properties after harvesting corn under different lime and phosphorus treatments.

Lime g kg ⁻¹	Phosphorus mg kg ⁻¹	pH H ₂ O	P --mg kg ⁻¹ --	K --	Ca -----cmol kg ⁻¹ ----	Mg -----	Al -----	Zn -----	Cu -----	Mn mg kg ⁻¹ -----	Fe -----
0	0	4.4	1.2	223	0.76	0.90	0.80	19	2.5	17	136
0	50	4.4	13.2	171	0.83	0.96	0.73	21	2.9	19	389
0	175	4.7	39.8	69	0.83	1.20	0.53	18	3.2	21	756
2	0	4.6	1.3	274	2.53	2.03	0.23	22	3.0	24	422
2	50	4.7	12.4	131	2.26	1.56	0.30	17	2.4	21	183
2	175	4.7	54.7	88	2.66	2.06	0.23	24	2.7	21	176
4	0	5.2	1.1	326	4.56	3.13	0.10	22	2.8	27	370
4	50	5.3	14.8	154	4.03	2.80	0.10	21	2.4	28	466
4	175	5.6	56.5	93	4.00	2.26	0.10	20	2.9	25	378

F-Test

Lime	**	NS	*	**	**	**	NS	NS	**	*
Phosphorus	**	**	**	NS	NS	NS	NS	NS	NS	NS
Lime X P	*	NS	**	*	**	NS	NS	NS	NS	**
C.V. %	1.8	27.8	15	7.96	14.17	33.62	19	13.5	11	18

Average across the lime (L) and P levels

L ₀	4.5c	18.1a	155b	0.81c	1.02c	0.69a	19a	2.9a	19c	427a
L ₂	4.7b	22.8a	165ab	2.48b	1.88b	0.26b	21a	2.7a	22b	260a
L ₄	5.4a	24.1a	191a	4.20a	2.73a	0.10c	21a	2.7a	26a	405a
P ₀	4.7b	1.2b	275a	2.62a	2.02a	0.38a	21a	2.8a	23a	309a
P ₅₀	4.8b	13.5b	152b	2.37b	1.78a	0.38a	19a	2.6a	22a	346a
P ₁₅₀	5.0a	50.4a	83c	2.50ab	1.84a	0.29a	21a	2.9a	22a	437a

*, **Significant at the 0.05 and 0.01 probability levels, respectively. NS = Not significant.

Within column means followed by a different letter differ significantly at $P < 0.05$ by Tukey's studentized range test.

enhancement of dry matter accumulation of common bean and corn, but lime addition significantly reduced top weight of rice and wheat. Since these two crops are tolerant to soil acidity, not much improvement could be achieved by liming. Phosphorus, in combination with lime, improved soil pH. Addition of 175 mg P/kg with 4 g lime/kg increased soil pH from 4.4 to 5.6 and reduced extractable Al from 0.80 to 0.10 cmol/kg. The pH of 5.0 was considered adequate for most crops in an Oxisol (Fageria et al., 1991). The extractable levels of Fe and Mn in these soils are dependent upon soil pH more than that of Zn and Cu. Therefore, by overliming one could expect deficiencies of Fe.

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